Introduction to Software Testing
(*2nd edition*)
Chapter 5

Criteria-Based Test Design

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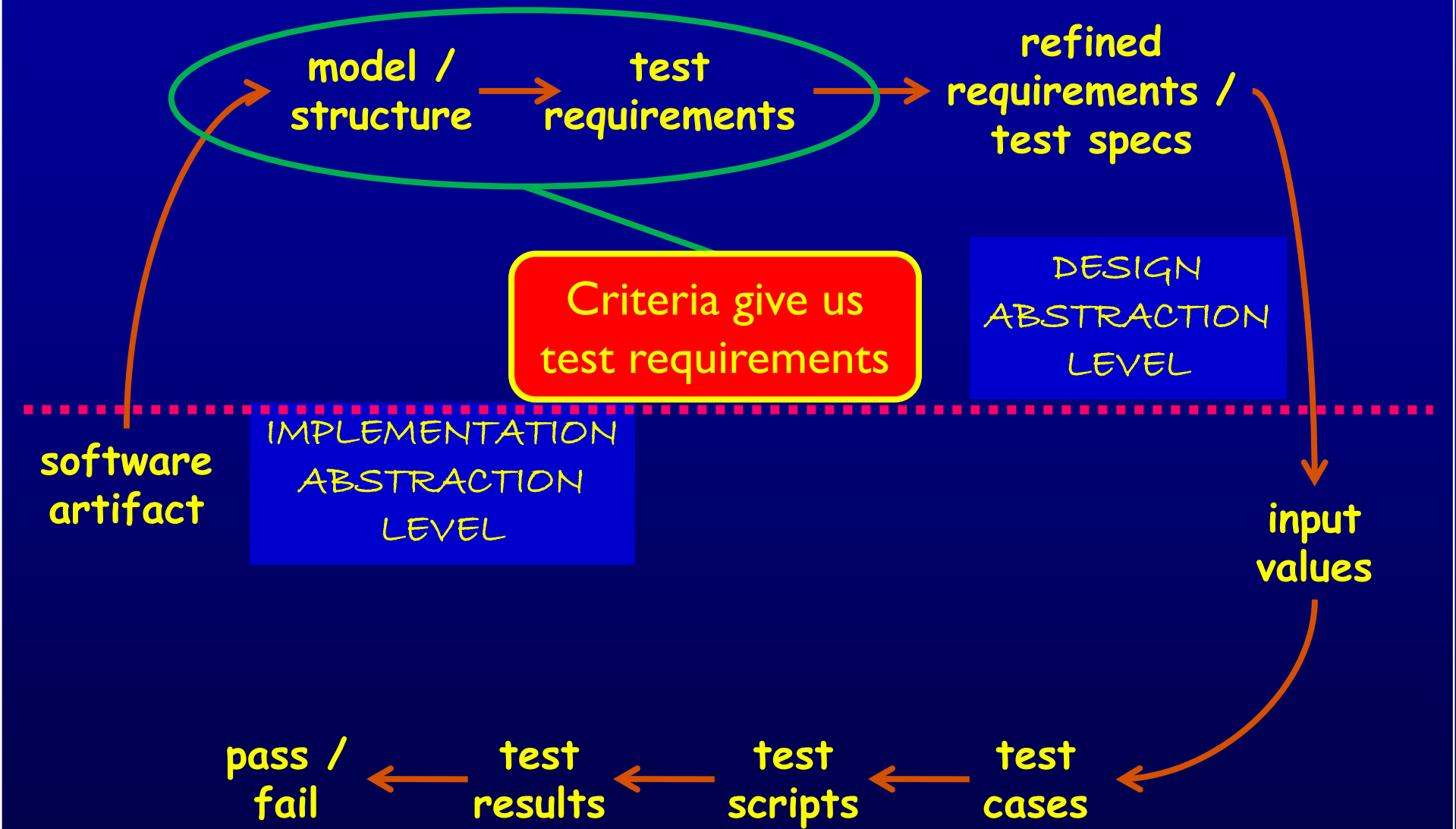
Changing Notions of Testing

- Old view focused on testing at each software development phase as being very different from other phases
  - Unit, module, integration, system …
- New view is in terms of structures and criteria
  - input space, graphs, logical expressions, syntax
- Test design is largely the same at each phase
  - Creating the model is different
  - Choosing values and automating the tests is different

Model-Driven Test Design



New : Test Coverage Criteria

A tester's job is simple : Define a model of the software, then find ways to cover it

- Test Requirements : A specific element of a software artifact that a test case must satisfy or cover

- Coverage Criterion : A rule or collection of rules that impose test requirements on a test set

Testing researchers have defined dozens of criteria, but they are all really just a few criteria on four types of structures …

Source of Structures

- These structures can be extracted from lots of software artifacts
  - Graphs can be extracted from UML use cases, finite state machines, source code, …
  - Logical expressions can be extracted from decisions in program source, guards on transitions, conditionals in use cases, …
- This is not the same as "*model-based testing*," which derives tests from a model that describes some aspects of the system under test
  - The model usually describes part of the behavior
  - The source is explicitly *not* considered a model

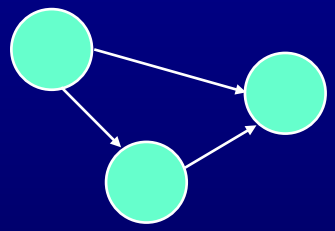
Criteria Based on Structures

Structures : Four ways to model software

1. Input Domain Characterization (sets)

   A: {0, 1, >1}
   B: {600, 700, 800}
   C: {swe, cs, isa, infs}

2. Graphs



3. Logical Expressions

   (not X or not Y) and A and B

4. Syntactic Structures (grammars)

```
if (x > y)
    z = x - y;
else
   z = 2 * x;
```

Example : Jelly Bean Coverage

Flavors :

1. Lemon
2. Pistachio
3. Cantaloupe
4. Pear
5. Tangerine
6. Apricot

Colors :

1. Yellow (Lemon, Apricot)
2. Green (Pistachio)
3. Orange (Cantaloupe, Tangerine)
4. White (Pear)

- Possible coverage criteria :
  1. Taste one jelly bean of each flavor
     - Deciding if yellow jelly bean is Lemon or Apricot is a controllability problem
  2. Taste one jelly bean of each color

Coverage

Given a set of test requirements *TR* for coverage criterion *C*, a test set *T* satisfies *C* coverage if and only if for every test requirement *tr* in *TR*, there is at least one test *t* in *T* such that *t* satisfies *tr*

- Infeasible test requirements : test requirements that cannot be satisfied
  - No test case values exist that meet the test requirements
  - Example: Dead code
  - Detection of infeasible test requirements is formally undecidable for most test criteria
- Thus, 100% coverage is impossible in practice

More Jelly Beans

T1 = { three Lemons, one Pistachio, two Cantaloupes, one Pear, one Tangerine, four Apricots }

- Does test set T1 satisfy the flavor criterion ?

T2 = { One Lemon, two Pistachios, one Pear, three Tangerines }

- Does test set T2 satisfy the flavor criterion ?
- Does test set T2 satisfy the color criterion ?

Coverage Level

The ratio of the number of test requirements satisfied by *T* to the size of *TR*

- T2 on the previous slide satisfies 4 of 6 test requirements

Two Ways to Use Test Criteria

1. Directly generate test values to satisfy the criterion
   - Often assumed by the research community
   - Most obvious way to use criteria
   - Very hard without automated tools
2. Generate test values externally and measure against the criterion
   - Usually favored by industry
   - Sometimes misleading
   - If tests do not reach 100% coverage, what does that mean?

Test criteria are sometimes called metrics

Generators and Recognizers

- Generator : A procedure that automatically generates values to satisfy a criterion
- Recognizer : A procedure that decides whether a given set of test values satisfies a criterion

- Both problems are provably undecidable for most criteria
- It is possible to recognize whether test cases satisfy a criterion far more often than it is possible to generate tests that satisfy the criterion

- Coverage analysis tools are quite plentiful

Comparing Criteria with Subsumption (5.2)

- Criteria Subsumption : A test criterion *C1* subsumes *C2* if and only if every set of test cases that satisfies criterion *C1* also satisfies *C2*
- Must be true for every set of test cases
- *Examples* :
  - The flavor criterion on jelly beans subsumes the color criterion … if we taste every flavor we taste one of every color
  - If a test set has covered every branch in a program (satisfied the branch criterion), then the test set is guaranteed to also have covered every statement

Advantages of Criteria-Based Test Design (5.3)

- Criteria maximize the "bang for the buck"
  - Fewer tests that are more effective at finding faults
- Comprehensive test set with minimal overlap
- Traceability from software artifacts to tests
  - The "why" for each test is answered
  - Built-in support for regression testing
- A "stopping rule" for testing—advance knowledge of how many tests are needed
- Natural to automate

Characteristics of a Good Coverage Criterion

1. It should be fairly easy to compute test requirements automatically
2. It should be efficient to generate test values
3. The resulting tests should reveal as many faults as possible

- Subsumption is only a rough approximation of fault revealing capability
- Researchers still need to gives us more data on how to compare coverage criteria

Test Coverage Criteria

- Traditional software testing is expensive and labor-intensive
- Formal coverage criteria are used to decide which test inputs to use
- More likely that the tester will find problems
- Greater assurance that the software is of high quality and reliability
- A goal or stopping rule for testing
- Criteria makes testing more efficient and effective

How do we start applying these ideas in practice?

How to Improve Testing ?

- Testers need more and better software tools
- Testers need to adopt practices and techniques that lead to more efficient and effective testing
  - More education
  - Different management organizational strategies
- Testing & QA teams need more technical expertise
  - Developer expertise has been increasing dramatically
- Testing & QA teams need to specialize more
  - This same trend happened for development in the 1990s

Four Roadblocks to Adoption

1. Lack of test education
   - Microsoft and Google say half their engineers are testers, programmers test half the time
   - Number of UG CS programs in US that require testing ? **0**
   - Number of MS CS programs in US that require testing ? **0**
   - Number of UG testing classes in the US ? **~50**
2. Necessity to change process
   - Adoption of many test techniques and tools require changes in development process
   - This is expensive for most software companies
3. Usability of tools
   - Many testing tools require the user to know the underlying theory to use them
   - Do we need to know how an internal combustion engine works to drive ?
   - Do we need to understand parsing and code generation to use a compiler ?
4. Weak and ineffective tools
   - Most test tools don't do much – but most users do not realize they could be better
   - Few tools solve the key technical problem – generating test values automatically

Needs From Researchers

1. Isolate : Invent processes and techniques that isolate the theory from most test practitioners
2. Disguise : Discover engineering techniques, standards and frameworks that disguise the theory
3. Embed : Theoretical ideas in tools
4. Experiment : Demonstrate economic value of criteria-based testing and ATDG (*ROI*)
   - Which criteria should be used and when ?
   - When does the extra effort pay off ?
5. Integrate high-end testing with development

Needs From Educators

1. Disguise theory from engineers in classes

2. Omit theory when it is not needed

3. Restructure curricula to teach more than test design and theory
   - Test automation
   - Test evaluation
   - Human-based testing
   - Test-driven development

Changes in Practice

1. Reorganize test and QA teams to make effective use of individual abilities
   - One math-head can support many testers
2. Retrain test and QA teams
   - Use a process like MDTD
   - Learn more testing concepts
3. Encourage researchers to embed and isolate
   - We are very responsive to research grants
4. Get involved in curricular design efforts through industrial advisory boards

Criteria Summary

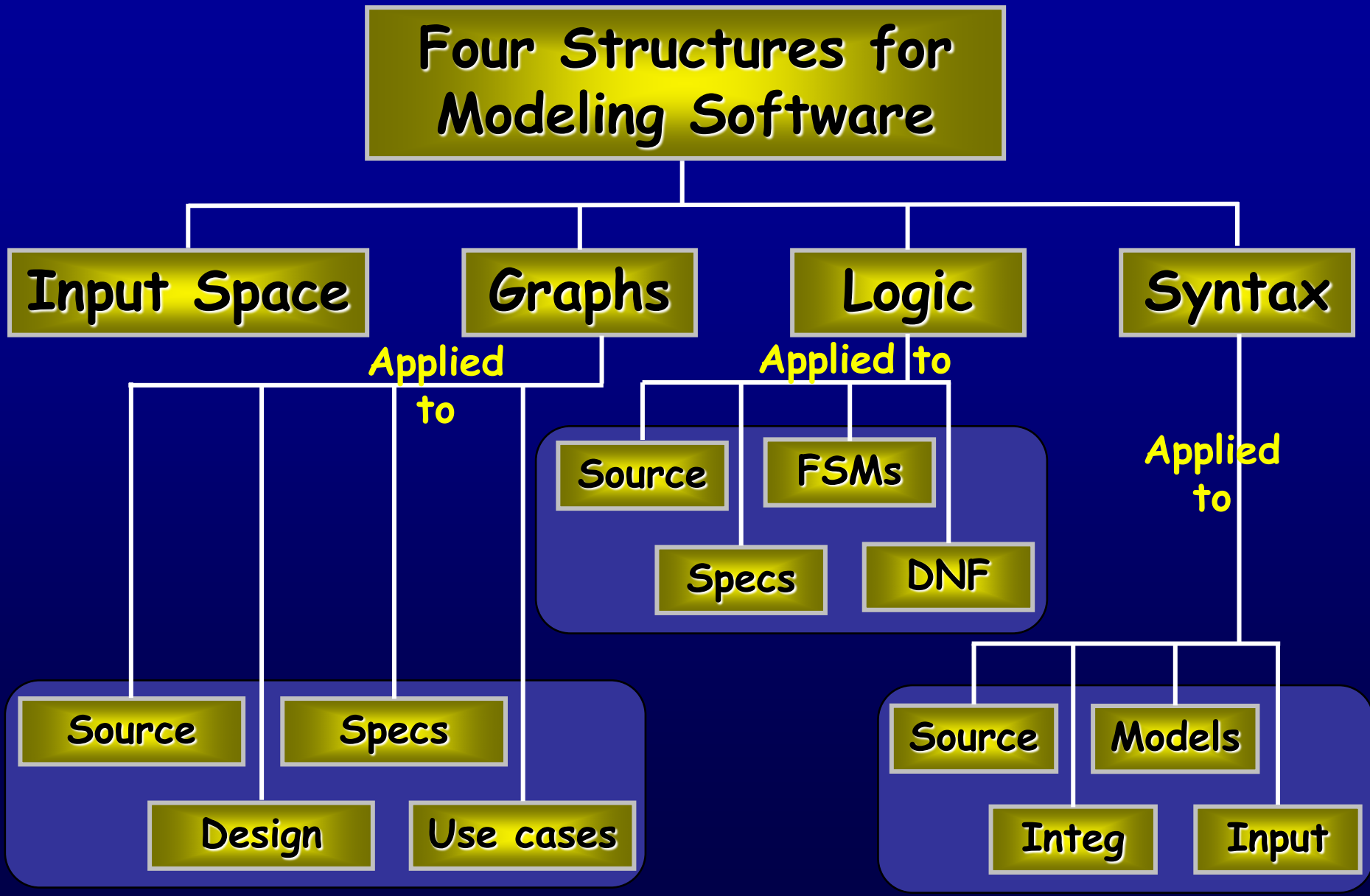
- Many companies still use "monkey testing"
  - A human sits at the keyboard, wiggles the mouse and bangs the keyboard
  - No automation
  - Minimal training required
- Some companies automate human-designed tests
- But companies that use both automation and criteria-based testing

Save money

Find more faults

Build better software

Structures for Criteria-Based Testing



Summary of Part 1's New Ideas

1. Why do we test – to reduce the risk of using software
   - Faults, failures, the RIPR model
   - Test process maturity levels – level 4 is a mental discipline that improves the quality of the software
2. Model-Driven Test Design
   - Four types of test activities – test design, automation, execution and evaluation
3. Test Automation
   - Testability, observability and controllability, test automation frameworks
4. Test Driven Development
5. Criteria-based test design
   - Four structures – test requirements and criteria

Earlier and better testing empowers test managers